

Application of GALDIT index to assess the intrinsic vulnerability to seawater intrusion of coastal granular aquifers

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Abstract Groundwater within coastal aquifers is considered a very sensitive natural resource since its quantity and quality is threatened by anthropogenic activities as well as global and climate changes. The major environmental hazard with respect to coastal aquifers is the phenomenon of seawater intrusion, and is more pronounced in the Mediterranean basin. In the light of smart management of such hydrogeological systems, GALDIT index was introduced in the form of a numerical ranking system that aims to assess the vulnerability of such aquifers to seawater intrusion. This paper provides an application of GALDIT vulnerability index for a typical Mediterranean alluvial aquifer under variable hydrogeological conditions in different research periods (1992 and 2004). The results proved the significance of the piezometric conditions of the aquifer with respect to its vulnerability to seawater intrusion.

Keywords GALDIT · Vulnerability index · Coastal hydrogeology · Seawater intrusion · Coastal aquifer management

Introduction

Water-bearing geological formations, such as aquifers, are susceptible to different types of quantitative or qualitative stresses, which are either anthropogenic or naturally originated. However, such hydrogeological systems do not always pose the same threat to their groundwater resources throughout their entire area of extent, but they seem to present a spatial variation with respect to their vulnerability. By definition, the term of aquifer vulnerability, implies that certain parts of the aquifer may provide protection for the containing groundwater while others behave differently. Vulnerability models or indexes were developed in order to provide the necessary managerial tools needed to map the spatial susceptibility of aquifer to contamination. Each one of the aforementioned is designed so that it incorporates the most critical parameters related to the environmental problem under investigation, resulting in a synthesis of various measurable components.

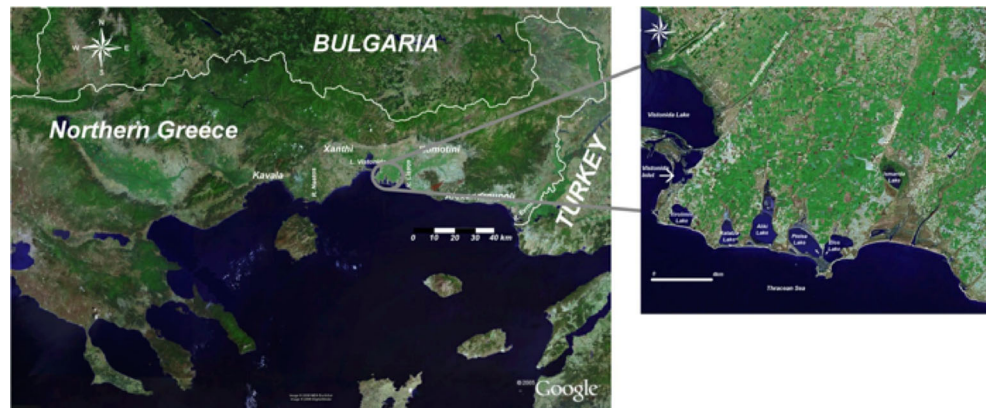
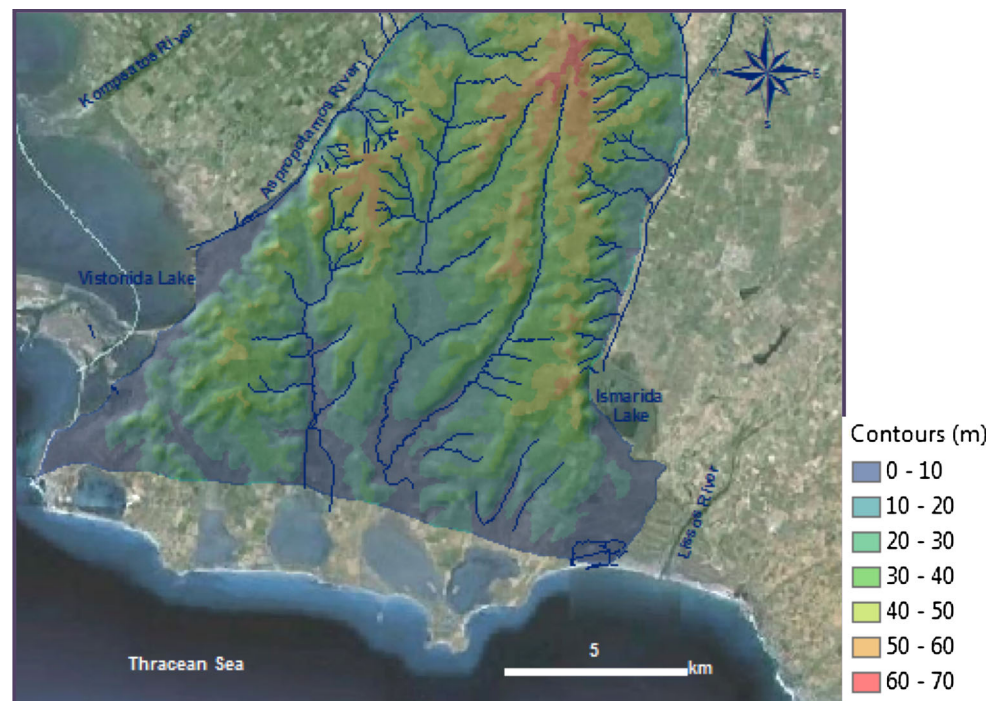
Such an important environmental problem, typical for the majority of exploited coastal aquifers in the Mediterranean is the phenomenon of seawater intrusion and groundwater salinization. A vast number of case studies have been widely investigated and reported in this region (Gaaloul 2014; Gaaloul et al. 2014; Rey et al. 2013; Saidi et al. 2013; Yousif and Bubenzer 2013; Farid et al. 2013; Elewa et al. 2013; Giudici et al. 2012; Gaaloul et al. 2012; Kharroubi et al. 2012; Trabelsi et al. 2012; Chaaban et al. 2012; Ben Cheikh et al. 2012; Ben Hamouda et al. 2012; Carneiro et al. 2012; Guler 2012; Guler et al. 2012; Plummer et al. 2012; Rodellas et al. 2012; Cobaner et al. 2012; Ben Hamouda et al. 2012; Guler et al. 2012; Baba and Tayfur 2011; Kaman et al. 2011; Yechieli and Sivan 2011; Al et al. 2011; Gossel et al. 2010; Kouzana et al. 2010; Carneiro et al. 2010; Seckin et al. 2010; Custodio

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Fig. 1 Study area location**Fig. 2** Digital elevation model of the area and hydrographic setting

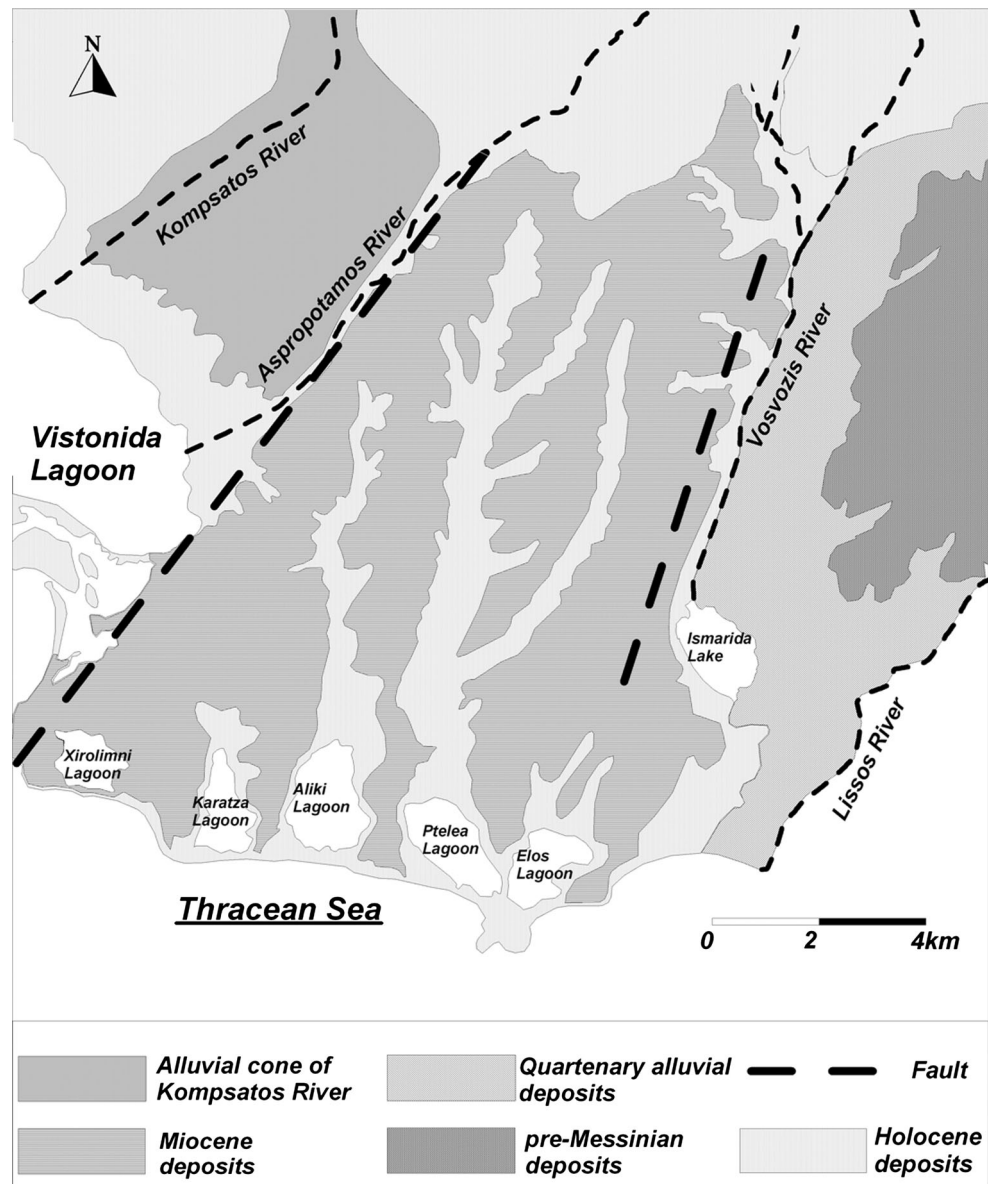
2010; Steyl and Dennis 2010; Jorreto et al. 2009; Yechieli et al. 2009; El Yaouti et al. 2009; Kouzana et al. 2009), and especially in Greece (Hamdan and Vafidis 2013; Gemtzi 2012; Sdao et al. 2012; Boskidis et al. 2012; Stamatis et al. 2006; Petalas and Lambrakis 2006; Lambrakis 2006; Lambrakis and Kallergis 2001; Pisinaras et al. 2010; Pisinaras et al. 2007; Zagana et al. 2007; Kallioras et al. 2010a, b; Kallioras et al. 2006; Koukadaki et al. 2007; Panagopoulos et al. 2004; Stamatis et al. 2001).

Chachadi and Lobo Ferreira (2001) realized the necessity for developing a numerical ranking system to assess the general seawater intrusion potential of each hydro-geologic setting. In this sense, it was concluded that the most important mappable factors that control the seawater intrusion are (Lobo Ferreira et al. 2005; Chachadi and Lobo-Ferreira 2005):

- Groundwater occurrence (aquifer type; unconfined, confined and leaky confined)
- Aquifer hydraulic conductivity
- Depth to groundwater Level above sea
- Distance from the shore (distance inland perpendicular from shoreline)
- Impact of existing status of seawater intrusion in the area
- Thickness of the aquifer which is being mapped.

As seen above, GALDIT vulnerability index (acronym resulted from the above parameters) involves measurable parameters which can be synthesized to provide an efficient tool for mapping the seawater intrusion potential of a coastal aquifer. Once the GALDIT index has been computed, it is possible to identify areas that are more likely to be susceptible to seawater intrusion than other areas. The

Fig. 3 Geological map of the study area (Kallioras et al. 2006)



higher the vulnerability index, the greater the seawater intrusion potential.

GALDIT index has been applied in several studies in order to assess the aquifer’s vulnerability to seawater intrusion (Chachadi and Lobo Ferreira 2001; Chachadi et al. 2002; Chachadi 2005; Kalyana Sundaram et al. 2008; Mahesha et al. 2012; Shetkar and Mahesha 2011; Sophiya and Syed 2013).

This paper presents the application of GALDIT vulnerability index in an alluvial coastal aquifer of northern Greece in order to identify the parts of the aquifer at which seawater intrusion potential is more pronounced. Field data from two different research periods were used (1992 and 2004) in order to appraise the effectiveness of such a tool as well as to analyze the sensitivity of certain hydrogeological parameters of the investigated aquifer

system with respect to seawater intrusion. The periods above are with regard to different piezometric conditions, illustrating a high contrast between groundwater levels within a decade.

Geographical, geological and geomorphological setting of the study area

The area under investigation is situated in northern-east Greece, at SW coastal plain part of the prefecture of Rhodope between the lakes Ismarida—at the western part—and Vistonida at the east. Apart from these two lakes, the area is bounded by the rivers Vosvozis and Aspropotamos in the east and west sides, respectively. The

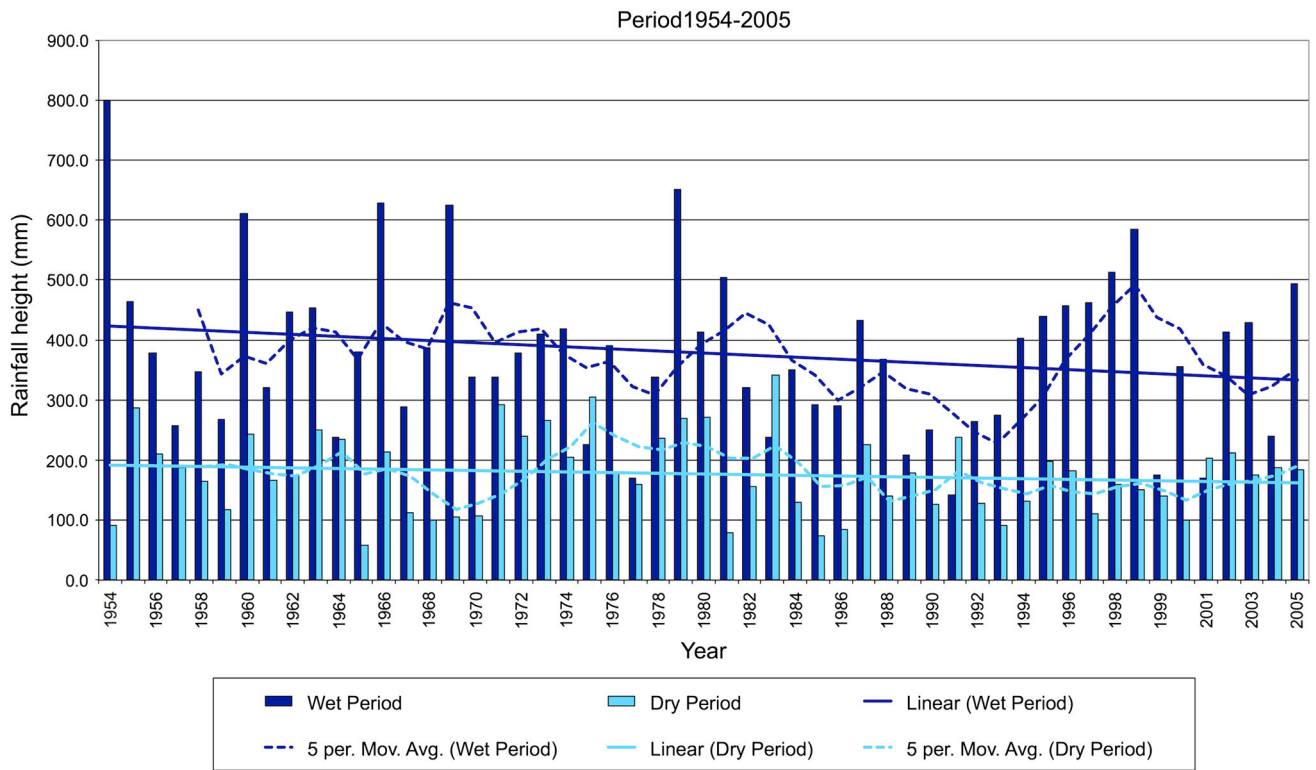


Fig. 4 Annual precipitation during the wet and dry periods between 1954 and 2005

Fig. 5 Piezometric map of the study area based on groundwater level recordings (relative to mean sea level) on April 2004 (prior the irrigation period)

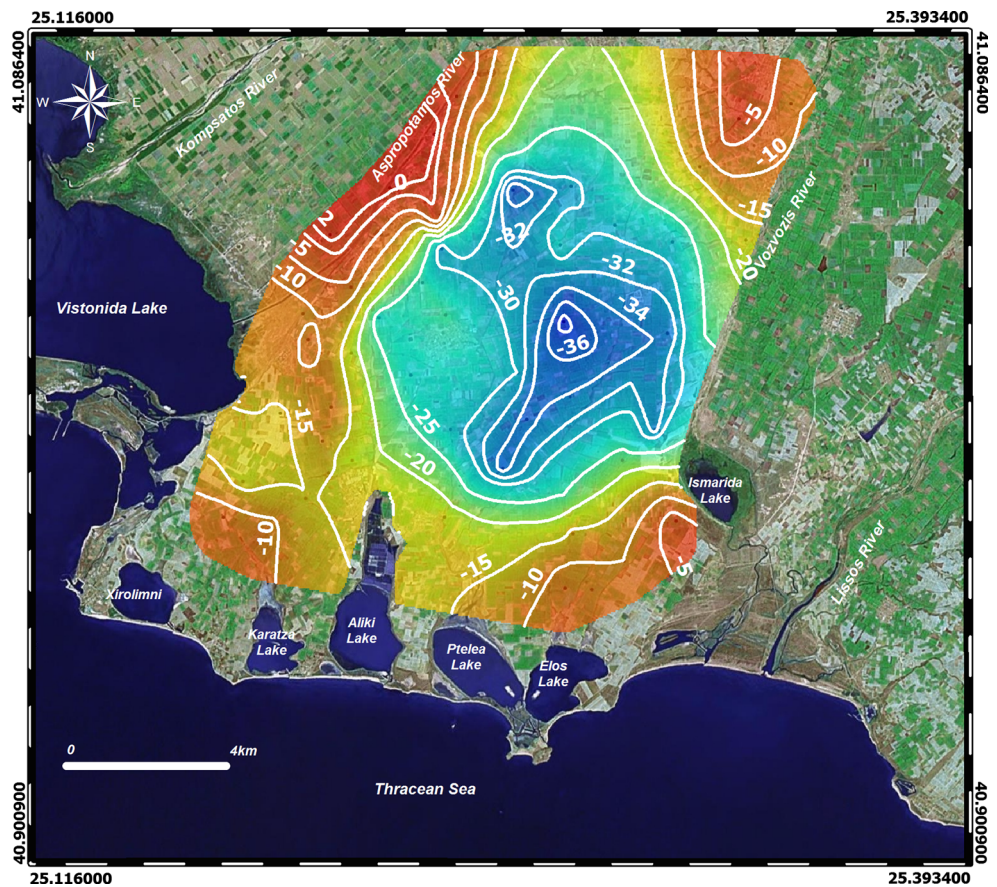
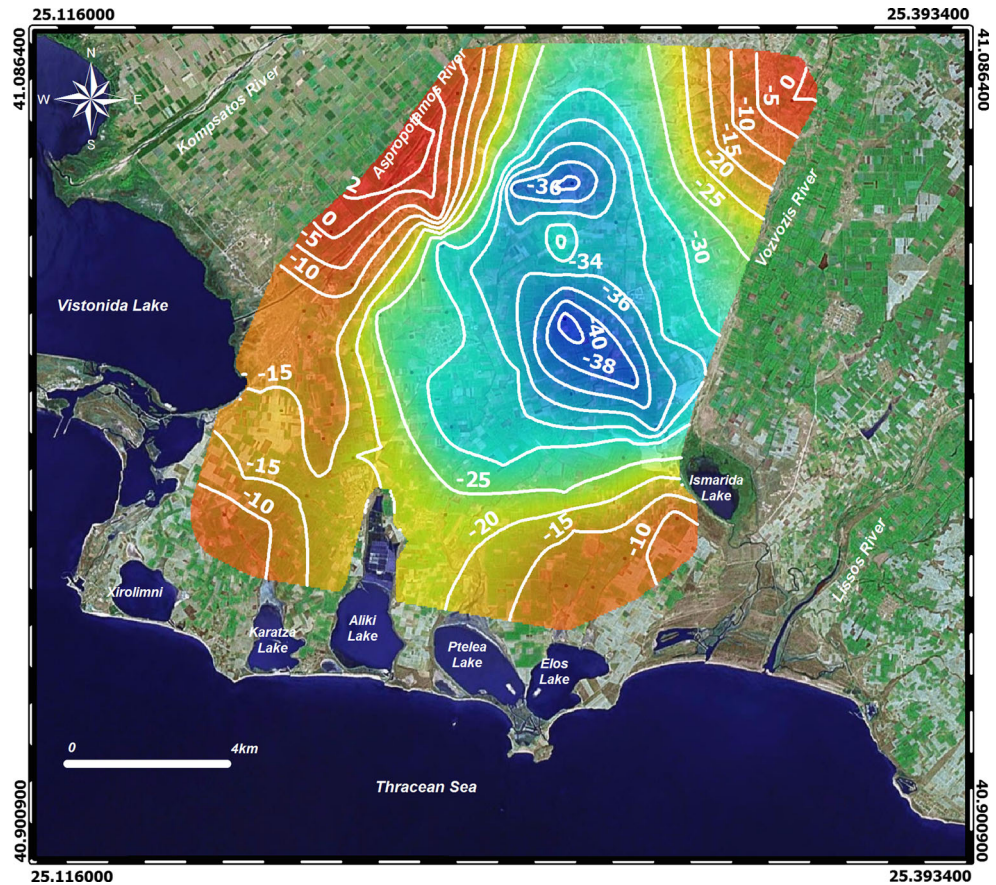


Fig. 6 Piezometric map of the study area based on groundwater level recordings (relative to mean sea level) on October 2004 (after the irrigation period)



coordinates (WGS 1984) of its boundaries range from 25.171825° to 25.341932° (longitude from W to E) and from 41.078614° to 40.961278° (latitude from N to S) (Fig. 1). The area of extent is approximately 160 km², containing at the southern part a series of coastal lakes which are hydraulically disconnected from the aquifer system in question (Kallioras et al. 2010a, b).

The topographic relief of the study area is mainly flat with some local semi-hilly and hilly parts (70 m being the highest altitude). The distribution of hills or ridges in the region form narrow valleys, which provide the preferential surface flowpaths for water runoff that locally contributes to groundwater recharge. Most of the study area presents slope ranges which do not exceed 12 %; however, approx. 75 % of the total area present low slopes values ranging from 1 to 4 % (Fig. 2) as shown in the digital elevation model (DEM).

The main geological formations of the study area are: (1) mudstones, sandstones, conglomerates and clays (which compose the upper geological formation responsible for the confined conditions of the aquifer system); (2) coarse-grained alluvial deposits (which compose the main aquifer layer); and finally, (3) the basement of the entire hydrogeological system which is composed of a grey-green clay layer (Fig. 3).

Hydro-meteorological and hydrogeological conditions of the study area

The climate of the study area is typical Mediterranean, with warm and dry summers as well as mild and wet winters. The hydrological conditions of the area for the period 1954–2005 show a wet period, from October to March, with an average precipitation of approx. 380 mm, while during the dry period—April to September—precipitation heights are rather low (approx. 175 mm in total during the period of 6 months). The average annual precipitation during the last 60 years is 555 mm, with November and December being the months where highest precipitation values have been recorded and July and August the months with highest temperatures and lowest precipitation heights. Annual precipitation data of the study area for the period 1954–2005 (Fig. 4) reveal a declining trend of annual precipitation for the wet periods of approximately 80 mm (Kallioras et al. 2010a, b).

The investigation of the aquifer’s hydraulic parameters resulted from a synthesis of pumping test results of previous investigations (Diamantis et al. 1994; Petalas 1997; Kallioras et al. 2006, 2010a, b). The pumping tests that carried out at 52 selected pumping wells (after 12 h of constant pumping rates) show typical values for alluvial aquifer layers composed of sands and gravels:

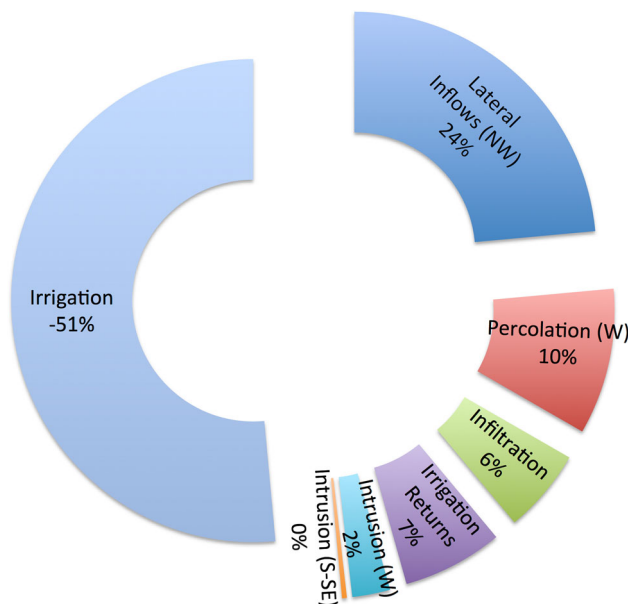
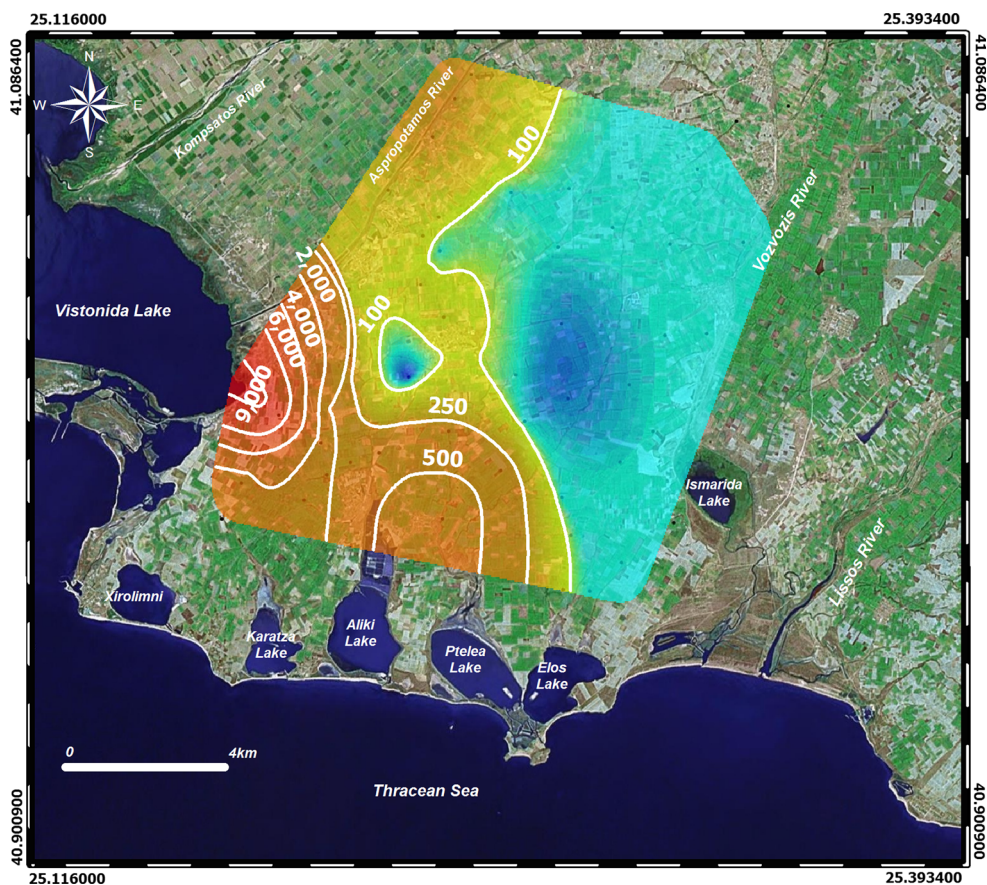


Fig. 7 Groundwater hydrologic balance of the investigated aquifer system

Transmissivity, T , ranges between 1.15×10^{-3} and $9.971 \times 10^{-2} \text{ m}^2/\text{s}$ (showing an average of $2.395 \times 10^{-2} \text{ m}^2/\text{s}$),

Fig. 8 Chloride (mg/L) distribution map in 1992 (chemical data source: Petalas 1997)



Hydraulic conductivity ranges between 2.49×10^{-5} and $2.22 \times 10^{-3} \text{ m/s}$, with an average value of $4.67 \times 10^{-4} \text{ m/s}$, and

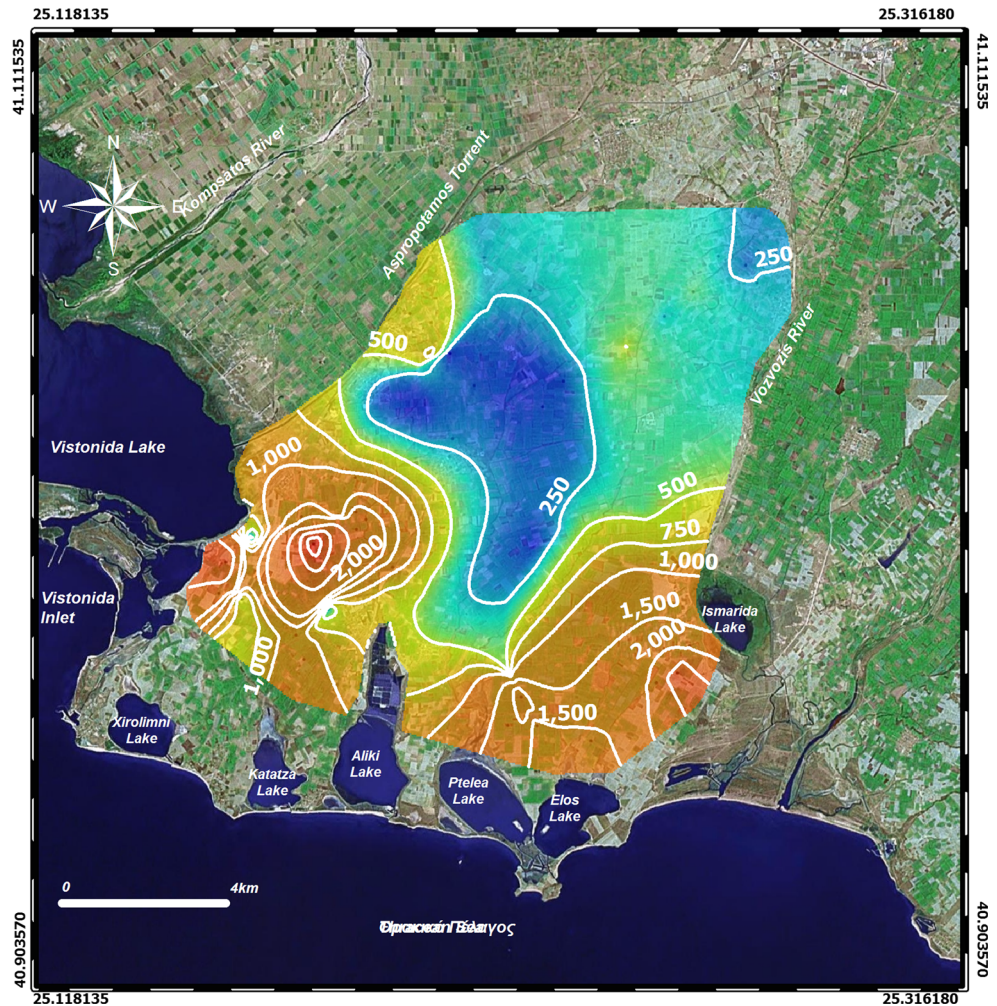
Storativity ranges between 1.3×10^{-4} and 2.9×10^{-2} with an average value of 5.06×10^{-3} .

The central part of the study area is under intensive groundwater exploitation, forming a constant deep cone of depression (-35 to -40 m groundwater levels) as it can be seen in the piezometric maps in Figs. 5 and 6. The pronounced period of drawdown, from April (Fig. 5) to October (Fig. 6), is related to extensive withdrawal rates for irrigation purposes.

Accurate determination of the groundwater hydrologic balance of an aquifer system is of ample importance for the “smart mining” of its groundwater resources. Following the above, Kallioras et al. (2010a, b) after simulating the groundwater hydrology of the investigated system concluded that:

- The most important groundwater inflows originate from the alluvial cone of Kompasatos River at the NW adjacent aquifer system, while the groundwater amounts which recharge the aquifer system of investigation account for $17.5 \times 10^6 \text{ m}^3$ which refer to 48.5 % of the total groundwater recharge;

Fig. 9 Chloride concentration (mg/L) distribution map in 2004



- Percolations from River Vozvozis as well as from the adjacent eastern aquifer system account for $7.3 \times 10^6 \text{ m}^3$ composing the 21.2 % of the total amount of groundwater recharge;
- The total amount of water which inflows into the aquifer system from direct infiltration from precipitation (natural recharge) and irrigation returns (incidental recharge) account for $4.2 \times 10^6 \text{ m}^3$ and $5 \times 10^6 \text{ m}^3$, respectively, both composing the 25.4 % of the total groundwater inflows;
- Groundwater inflows of 1.9×10^6 and $0.2 \times 10^6 \text{ m}^3$ were considered as lateral recharge of saline water (intruded seawater) at Vistonida inlet (western boundary) and at the southern part of Ismarida Lake (eastern boundary). Geophysical and drilling data from previous investigations (Diamantis et al. 1994) have proved that the aquifer system is hydraulically disconnected from the Ismarida as well as the set of the series of coastal lakes at the southern boundaries of the study area.

Figure 7 schematically represents the amounts of groundwater which are considered as water inflows $36 \times 10^6 \text{ m}^3$ and water outflows $38.2 \times 10^6 \text{ m}^3$ of the simulated aquifer system.

Chloride is a major chemical constituent of groundwater, while its concentration varies depending on: (1) natural conditions, such as the geology of the aquifer matrix (weathering and leaching of rocks and soils and the dissolution of salt deposits may release chlorides into the water) and/or (2) anthropogenic activities such as leaching from waste disposal sites, road salt applications and many others. Especially for the case of coastal aquifers, seawater intrusion is an additional cause for chlorides increase as it inevitably takes place since the aquifer is in hydraulic connection with the sea. However, certain anthropogenic activities such as intense groundwater mining that exceeds the safe yield of the aquifer in most of the cases causes inversion of the hydraulic gradient resulting in active seawater intrusion. Chloride in seawater intrusion studies is considered a “safe” indicator for the assessment of the

Table 1 Range and ratings for groundwater occurrence (Lobo Ferreira et al. 2005; Chachadi and Lobo-Ferreira 2005)

Groundwater occurrence	
Range	Rating
Confined aquifer	10
Unconfined aquifer	7.5
Leaky confined aquifer	5
Bounded aquifer (recharge and/or impervious boundary aligned parallel to the coast)	2.5

Table 2 Range and ratings for hydraulic conductivity (Lobo Ferreira et al. 2005; Chachadi and Lobo-Ferreira 2005)

Hydraulic conductivity (m/day)	
Range	Rating
>40	10
10–40	7.5
5–10	5
<5	2.5

aquifer’s contamination due to its conservative ionic behavior, because it does not participate in certain sorption processes (ion exchange); thus, acting as an effective indicator or tracer of the seawater wedge.

Figures 8 and 9 show the spatial distribution of chlorides in the study aquifer for the periods 1992 and 2004; with 500 mg/L being set as an indicative concentration with respect to the salt tolerance of cotton, the major cultivation type of the study area. It is observed that for the 1992 period, chloride concentrations higher than 500 mg/L are only observed at the west side of the area; while for 2004, higher chloride concentrations ranging from 500 to 5,000 mg/L can be observed at the SE part of the aquifer. The observed increase in chloride concentration throughout the aforementioned coastal fronts is a direct effect of the over-pumping of groundwater, which can be considered as being the most typical irrigation policy during the last 30 years in the area. A critical correlation between the chloride spatial distribution of 1992 and 2004 reveals that the extent of the aquifer’s contamination due to seawater intrusion has increased by 25 %.

Application of GALDIT vulnerability index in the study area

GALDIT index can predict the aquifer’s vulnerability to seawater intrusion by combining hydrogeological and morphological data describing the state of the aquifer under

Fig. 10 Hydraulic conductivity distribution ($\times 10^{-5}$ m/s)

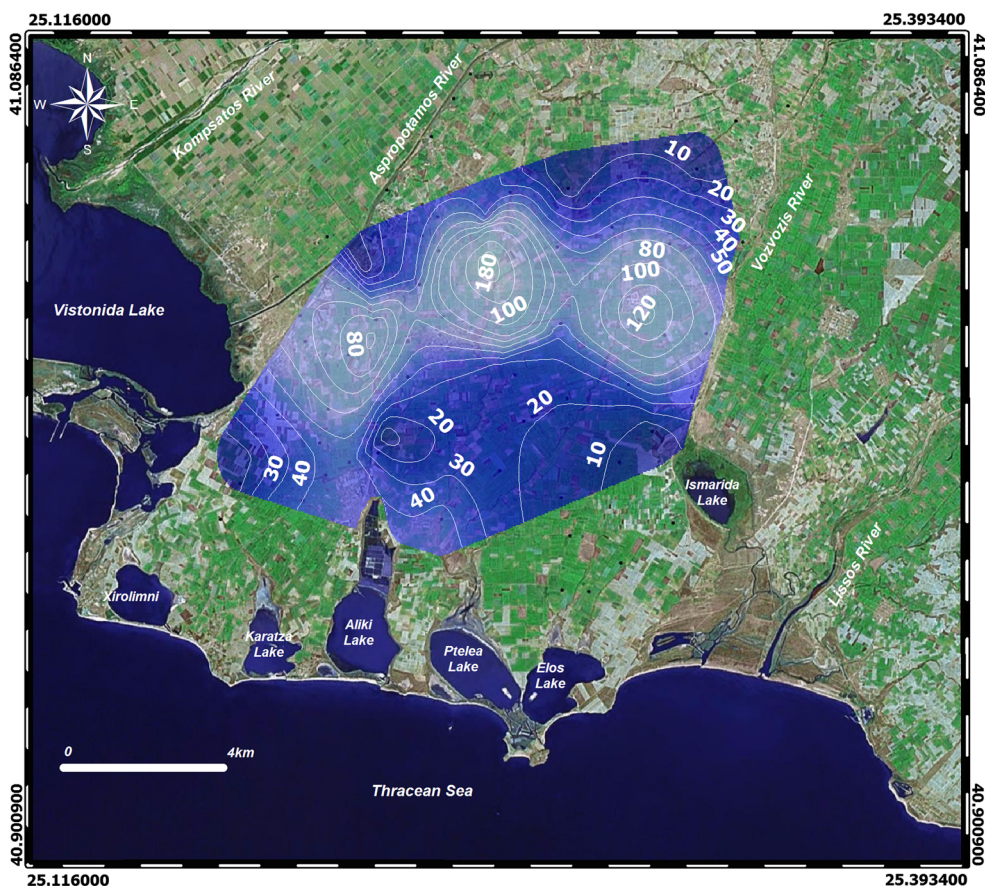


Table 3 Range and ratings for height of groundwater level above sea (Lobo Ferreira et al. 2005; Chachadi and Lobo-Ferreira 2005)

Height of groundwater level above sea (m)	
Range	Rating
<1.0	10
1.0–1.5	7.5
1.5–2.0	5
>2.0	2.5

investigation and categorizing the data into different parameters which are rated and weighted accordingly, and finally combined in the GALDIT equation.

In order to adjust, apply and evaluate the GALDIT vulnerability index for the investigated aquifer system, this study employed data from different research periods, i.e., 2004 (Kallioras 2008) and 1992 (Petalas 1997). Hence, 1992 was considered as the initial aquifer conditions, which were used in order to: (1) evaluate the ability of the index in question to predict the extension of the aquifer’s contamination in the future and (2) identify the most critical factors which govern the salinity spatial distribution patterns within the aquifer.

GALDIT “static” parameters that do not change significantly over time are: aquifer type (groundwater

occurrence), aquifer hydraulic conductivity, distance of the point of interest from the shoreline, and aquifer thickness; while the “dynamic” ones concerning temporal variability are mainly the height of groundwater level above sea elevation—which is considered that seriously modifies the hydrogeological regime of the aquifer—as well as the spatial distribution of chlorides (or Revelle coefficient).

GALDIT, as a numerical ranking system to assess sea-water intrusion potential in hydrogeologic settings has been developed using some certain parameters, each one involving the following significant parts: weights (1–4), ranges, and ratings (1–10).

The local index of vulnerability is computed through multiplication of the value attributed to each parameter (rating) by its relative weight and adding up all six products, following the expression (Lobo Ferreira et al. 2005; Chachadi and Lobo-Ferreira 2005):

$$\text{GALDIT} = \frac{1 \times G + 3 \times A + 4 \times L + 4 \times D + 1 \times I + 2 \times T}{15}$$

where, the numerical coefficients are the weights (already set up) and the G, A, L, D, I and T are the ratings of factors involved in GALDIT vulnerability index. The minimum value of the GALDIT index is 1 and the maximum value is 15.

Fig. 11 Height of groundwater level (m) above sea elevation distribution 1992 (water level data source: Petalas 1997)

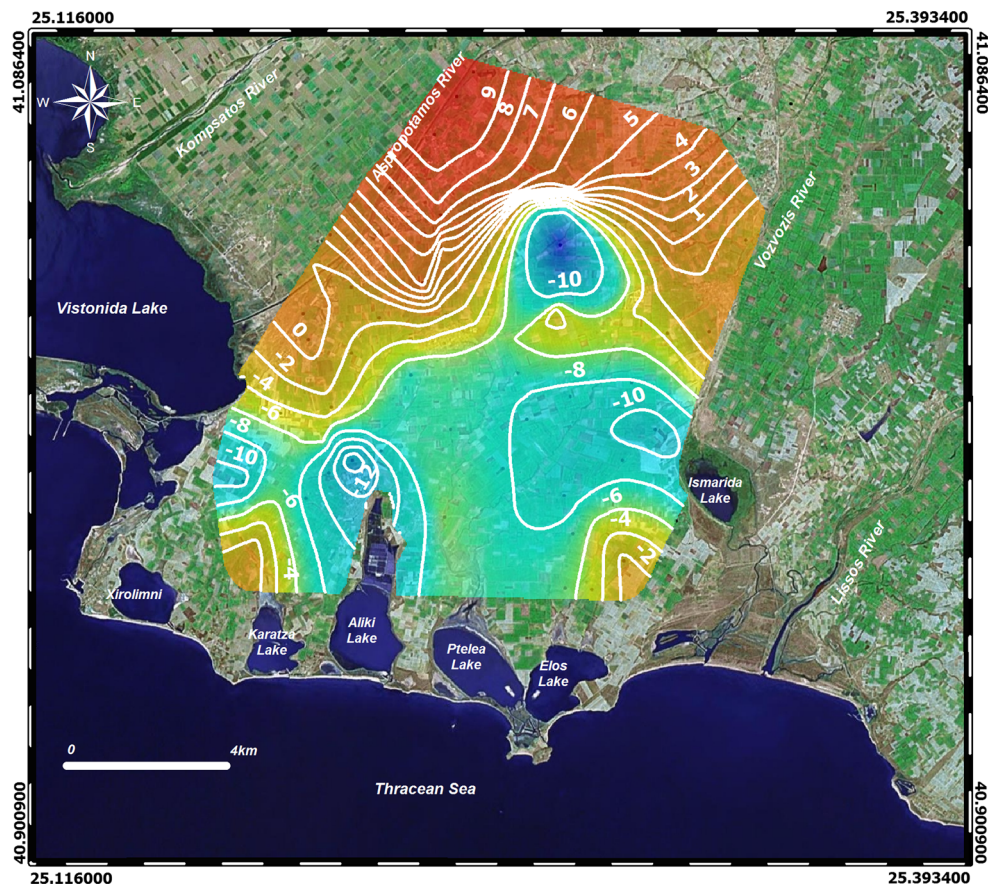
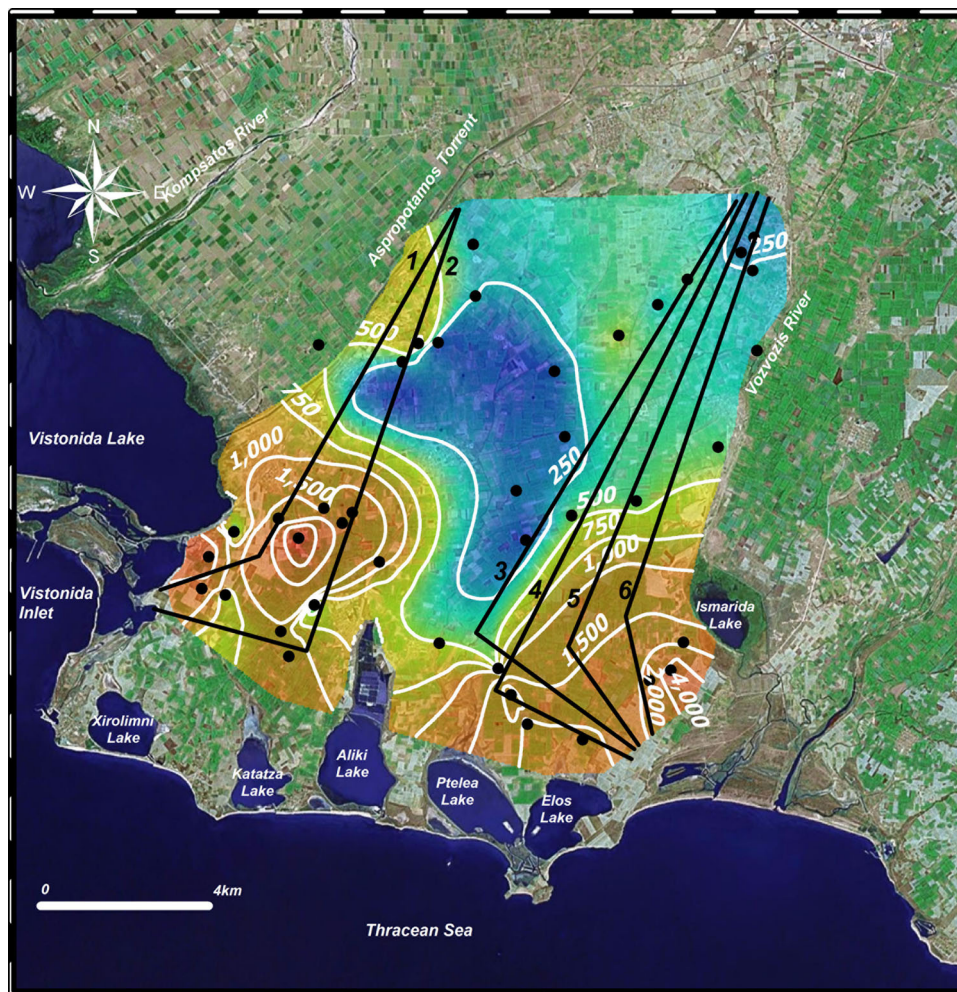


Fig. 12 Location of profiles 1–6 and chloride concentration distribution in the study area



The following sections (§4.1 to §4.7) use the hydro-geologic settings of the coastal aquifer in N. Greece as a mappable unit, and next, by modifying specific conditions and choosing corresponding ratings, the GALDIT index is developed, that shows the aquifer's vulnerability to seawater intrusion.

(G)—Groundwater occurrence

Parameter (G)—groundwater occurrence represents the aquifer type of the study area. For the case of the area under investigation, the aquifer is considered as semi-confined to confined, with the confining layer being composed of sandstone, mudstone and clay, hence the rating value for this parameter is 10, according to the GALDIT model rating table (Table 1).

(A)—Aquifer hydraulic conductivity

Parameter (A)—aquifer hydraulic conductivity is considered as a measure of the water movement rate (in the

horizontal direction of flow) through the saturated zone. The magnitude of seawater front movement is influenced by hydraulic conductivity; the higher the conductivity, the higher the inland movements of the seawater front (Lobo Ferreira et al. 2005; Chachadi and Lobo-Ferreira 2005).

According to GALDIT index, parameter rating values range from 2.5 to 10 (Table 2) for minimum and maximum vulnerability impact, respectively, for each well location. The study area has a zone of considerable hydraulic conductivity at the center part, ranging between 4×10^{-4} and 8×10^{-4} m/s (Fig. 10), which results in vulnerability ratings of 8–10 for this zone according to GALDIT classification.

(L)—Height of groundwater level above sea level

Parameter (L)—height of groundwater level above sea level, primarily refers to the piezometric conditions of the investigated coastal aquifer and is considered as a dynamic parameter, due to its temporal variation. Its importance for the hydraulic interpretation of the seawater intrusion mechanism can be realized from the simplified and

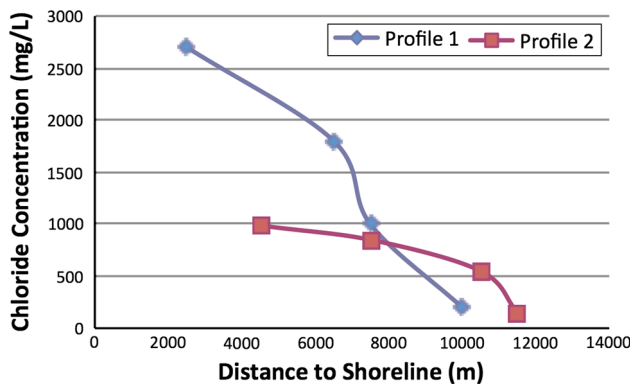


Fig. 13 Profiles 1 and 2, defining relation between chloride concentration and distance to shoreline at the west side

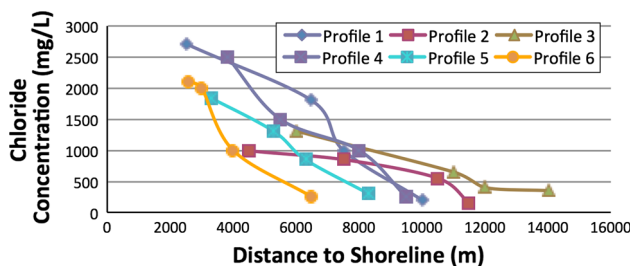


Fig. 14 Profiles 3–6, defining relation between chloride concentration and distance to shoreline at the east side

Table 4 Modified rating values for the GALDIT method parameter of distance to shoreline (Lobo Ferreira et al. 2005; Chachadi and Lobo-Ferreira 2005)

Modified distance from the shore (m)	
Range	Rating
<2,500	10
2,500–5,000	7.5
5,000–10,000	5
>10,000	2.5

Table 5 Range and ratings for impact status of existing seawater intrusion (Lobo Ferreira et al. 2005; Chachadi and Lobo-Ferreira 2005)

Impact status of existing seawater intrusion Cl ⁻ (mg/L)	
Range	Rating
>500	10
250–500	7.5
100–250	5
<100	2.5

theoretical approach of the so-called Ghyben–Herzberg principle (based on work of the pioneer researchers W. Badon-Ghijben, 1888, 1889 and A. Herzberg, 1901).

Table 6 Range and ratings for aquifer thickness (Lobo Ferreira et al. 2005; Chachadi and Lobo-Ferreira 2005)

Aquifer thickness (m)	
Range	Rating
>10	10
7.5–10	7.5
5–7.5	5
<5	2.5

GALDIT index assigns rates which range between 2.5 (minimum vulnerability impact) and 10 (maximum vulnerability impact), at each well location (Table 3). The spatial distribution of the data from 1992 show that approximately 75 % of the area has a piezometric surface below mean sea level (Fig. 11), hence GALDIT rating values for this parameter range between 3 and 10.

An extended decline of the piezometric surface of the aquifer system during the period 1992–2004 shows that more than 90 % of the area falls in the case where groundwater table levels are below the seawater level at present state, and the area has therefore parameter ranged between 4 and 10.

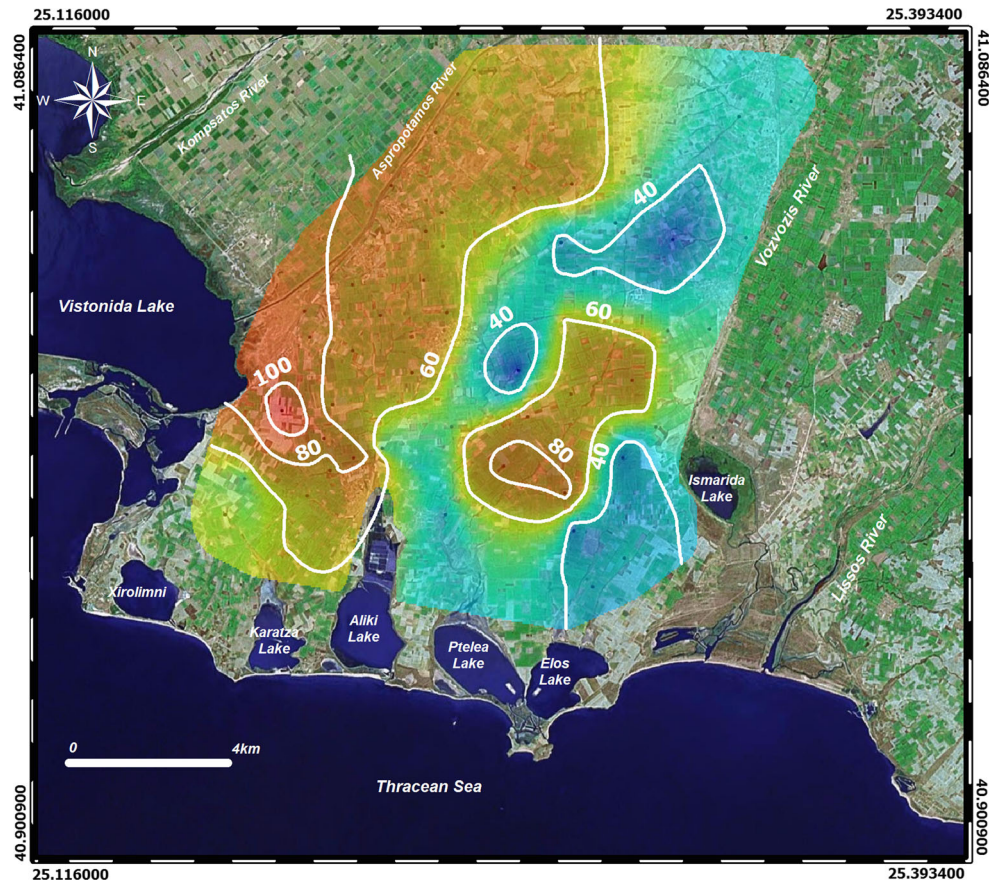
(D)—Distance from the point of interest to the shoreline

It can be observed from the spatial distribution of chlorides in 1992 and 2004—Figs. 8 and 9, respectively—that the initial conditions of the aquifer (i.e., 1992) involve a distinct seawater intrusion front which is located at the western coastal part of the aquifer while after a period of more than 10 years, a second front is identified at the SE coastal part of the study area.

Since this observation had to be incorporated in the GALDIT index in question, the study area was divided into two parts, western and eastern, as shown in Fig. 12. Consequently, six profiles (Figs. 13, 14) were then designed (west and east sides separately). Accordingly, four intervals towards the shoreline axis were designed in order to obtain the parameter of distance to shoreline, and a modified rating table for that GALDIT parameter is proposed (Table 4).

The parameter of distance to shoreline could then be calculated by measuring the distance from the different monitoring well points to the closest shoreline (east or west). The distances were classified by assigning GALDIT rating values according to the modified rating table for the parameter (shown above) ranging from 2.5 (minimum vulnerability impact) to 10 (maximum vulnerability impact), for each well location.

Fig. 15 Aquifer thickness distribution map (m)



(I)—Impact magnitude of existing seawater intrusion

This parameter refers to additional conditions which stress natural hydraulic balance between seawater and fresh groundwater. The impact of existing status of seawater intrusion is normally assessed using Revelle coefficient values distributed in the area. For the purpose of this investigation, since no data from bicarbonate ion analysis were available for 1992, the modified GALDIT-I parameter was calculated by using chloride concentration as a (Table 5).

Data concerning the chloride concentrations were obtained for different monitoring points and then corresponding values were classified by assigning GALDIT rating values, 2.5–10 for minimum and maximum, respectively.

For the year 1992 the GALDIT-I parameter was rated using values of 3 for location where chloride concentrations were low, to 10 where chlorides reach concentrations were measured above 5,000 mg/L (Fig. 8).

(T)—Aquifer thickness

This parameter represents the thickness of the saturated zone, hence can be calculated since the difference between

the groundwater table and the clay layer (bottom of the aquifer system) is known (Table 6).

The data were then classified by assigning to each well location the respective GALDIT rating value. The aquifer thickness in the study area ranges from 30 to 110 m; therefore, the value of 10 (for high vulnerability impact) was assigned since the aquifer thickness in the whole area exceeds the 10 m proposed by GALDIT index (Fig. 15).

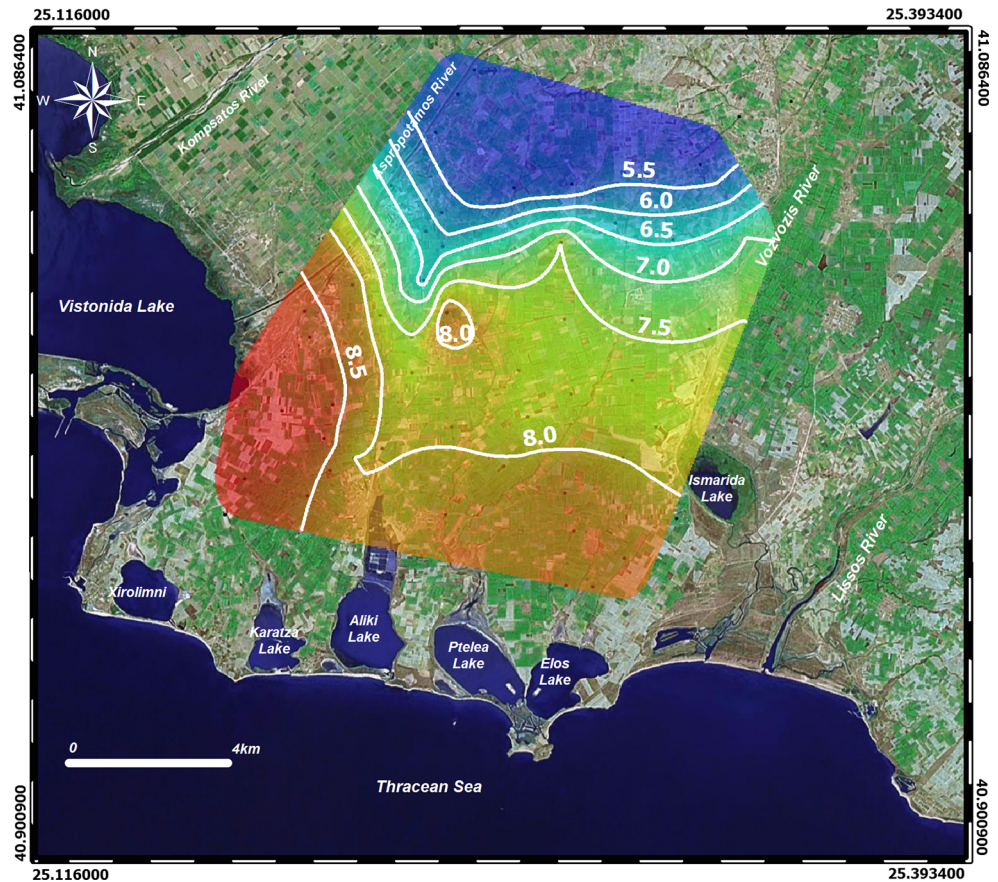
GALDIT indices

After calculating each GALDIT parameter, as analyzed in §4.1 to §4.6, the vulnerability index maps were designed for each single research period 1992 and 2004.

The GALDIT vulnerability index that corresponds to 1992 hydrogeological conditions, ranges between 5.5 and 9, and hence considered as moderate and high (Fig. 16). Approximately 45 % of the area corresponds to high vulnerability characterization, having indexes above 7.5, mainly located at the southern part of the area and extending approximately 7 km to the north.

For the application of GALDIT for 2004, the groundwater vulnerability index depicts values from 6

Fig. 16 GALDIT groundwater vulnerability index distribution 1992



to 9, describing moderate to high vulnerability conditions; whereas, in this case an area of extent of approximately 60 % shows indexes above 7.5 (Fig. 17). The high groundwater vulnerability indexes are identified at the southern part of the area extending up to 11.5 km towards the mainland (northern boundaries).

Conclusions and discussion

Seawater intrusion is a major environmental threat for groundwater resources, and since a large portion of global population is located within the coastal zone, this phenomenon has also social and economic dimensions. The above is more pronounced in the coastal aquifers of the Mediterranean basin, which are expected to suffer from additional stresses such as climate and global changes. For these reasons, different vulnerability models were developed in order to provide integrated assessment of the aquifer’s most vulnerable zones to seawater intrusion potential. GALDIT is such a vulnerability index, which is widely used to identify zones of variable degree of seawater intrusion

potential, and for this purpose it was also used in this study.

The investigated aquifer system is located in N. Greece and is the major source of freshwater in an area which is exclusively used for agricultural purposes, with irrigation being the main water use. Continuous monitoring of the piezometric conditions of the aquifer has proved that the abstraction rates since the beginning of the 1980s exceeded the aquifer’s natural replenishment, a fact which has resulted in a decrease of the piezometric surface of almost 35 m at some regions (Fig. 18). Since the aquifer’s piezometric conditions are dramatically changing during the last decades, the GALDIT vulnerability index which was used in this case, considered two separate research periods, 1992 and 2004.

The mapped output of GALDIT model presents the spatial distribution of the intrinsic vulnerability to seawater intrusion, showing that in the year of 1992, approximately 45 % of the area is subjected to high vulnerability conditions; whereas, the rest of the area poses moderate vulnerability to seawater intrusion. The area under highly vulnerable part extends up to 7 km far from the shoreline to the inland, covering most of the southern part of the study

Fig. 17 GALDIT groundwater vulnerability index distribution period 2003–2005

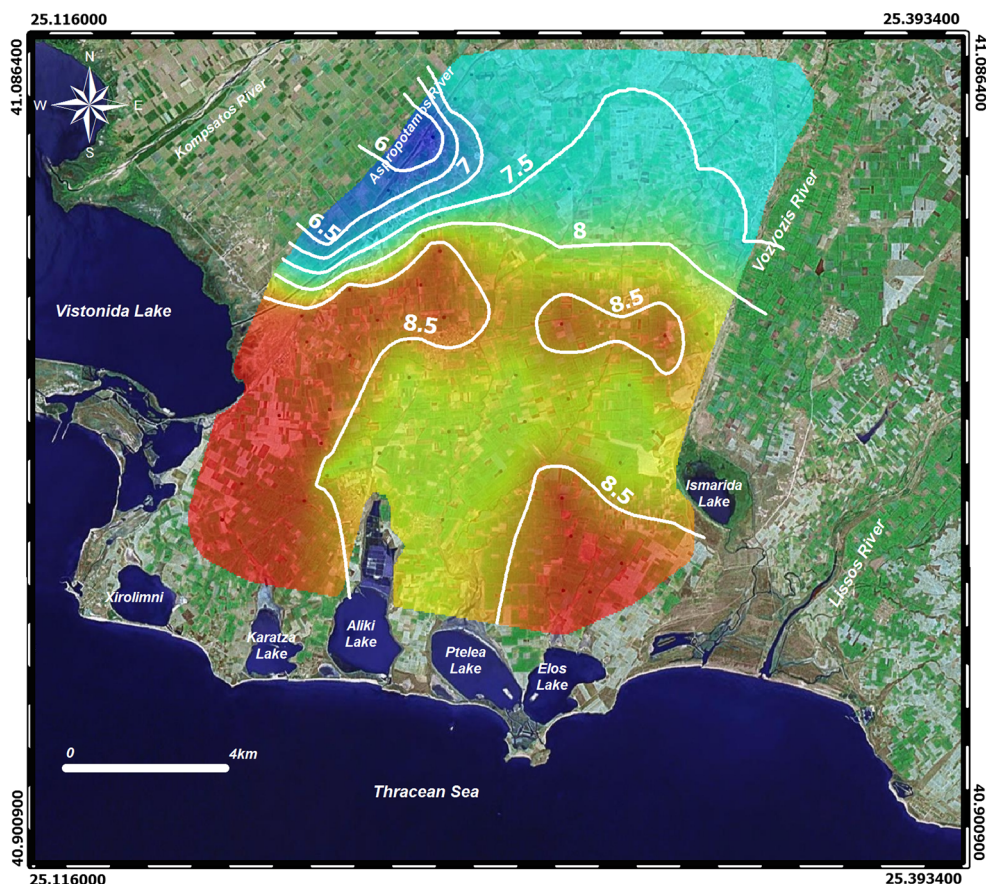
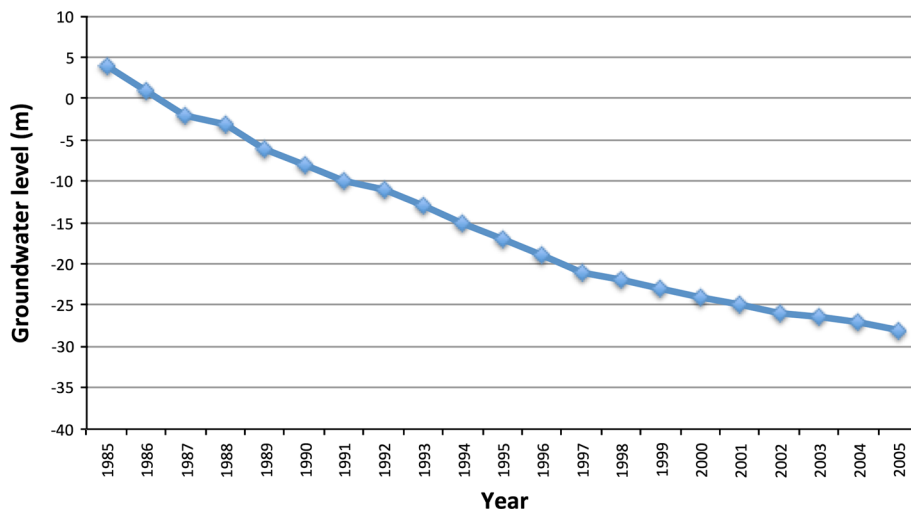


Fig. 18 Groundwater level drop down during the period 1985–2005 (updated from Diamantis et al. 1994; Petalas 1997; Petalas and Lambrakis 2006)



area where concentrations of chloride exceed 500 mg/L and groundwater levels are 5–10 m below mean sea level. Regarding the second research period, GALDIT index depicts that 60 % of the area is subject to high vulnerability conditions.

The difference in groundwater vulnerability to seawater intrusion regime between 1992 and 2004 is quite distinct, since 15 % of the area vulnerability characterization has

shifted from moderate vulnerability (1992) to high vulnerability (2004). According to the GALDIT parameter analysis of this study, it is concluded that the major cause for this observation is the dramatic decline of the groundwater level of the study aquifer. The formation of a deep cone of depression has caused a major disturbance in the hydrodynamic balance between fresh water and sea water, which resulted in further encroachment of the seawater

towards the inland. Therefore, (L)—height of groundwater level above sea level and (I)—impact magnitude of existing seawater intrusion, are the critical parameters which were crucially altered due to overexploitation for irrigation purposes, fact which increased the GALDIT vulnerability index for the investigated area.

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